Potential Difference, or Voltage

Because electrons are very small and carry very little energy, it is more useful to describe the work done on a *coulomb* of charge (recall from electrostatics that one coulomb (C) = 6.24 x 10^{18} electrons). This is the definition of potential difference, or voltage **ΔV**:

$$\mathbf{\Delta V = \frac{\Delta E_p}{q}} \qquad \text{or} \qquad \mathbf{\Delta E_p = q\Delta V}$$

→ where **ΔV** is measured in volts (**V**) or Joules/coulomb

Since the work done to separate charges is positive, the potential difference between the terminals in a cell is also positive. On the other hand, as charges flow through devices contained within a circuit, work is done *by* the system and the potential difference across each device is negative.

Example #4: If a chemical cell gives 600 J of energy to a charge of 50 C, what is the potential difference of this cell?

(see Circuitry Ex 4 for answer)

Note that in circuitry, the symbol for potential difference (also called *voltage*) is simply "**V**"; the delta sign **Δ** is dropped for simplicity.

Kirchhoff's Voltage Law

Kirchhoff also examined the potential difference in circuits. He found that, from the law of conservation of energy: the sum of the gains and drops in potential energy around any closed circuit path must equal zero, **or** in any complete circuit loop, the sum of the gains in potential difference (batteries) is equal to the sum of the potential drops (resistors). We can use this general principle to describe voltage rules for both series and parallel circuits:

- In a simple, one loop series circuit, the voltage drops across the various resistors = the potential difference of the voltage supply. Put another way, the potential difference of the voltage supply $\mathbf{V_o}$ is equal to the sum of the potential "drops" across each of the components $\mathbf{V_1}$, $\mathbf{V_2}$, $\mathbf{V_3}$...etc. That is,

$$\mathbf{V_o = V_1 + V_2 + V_3 + ...}$$

➢ In a circuit with parallel circuit paths, the total potential difference across each parallel branch must be equal; that is,

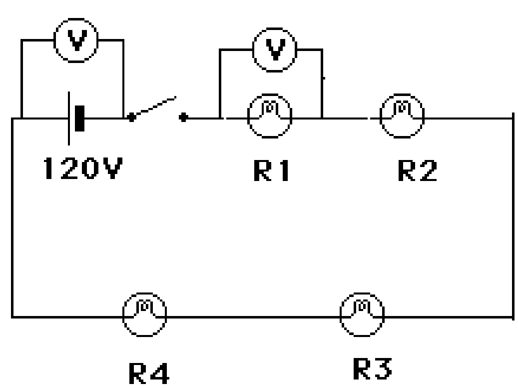
$$\mathbf{V_o = V_1 = V_2 = V_3 = ...}$$

There is a simple skiing analogy that can be used to determine voltage drops at various locations in a circuit:

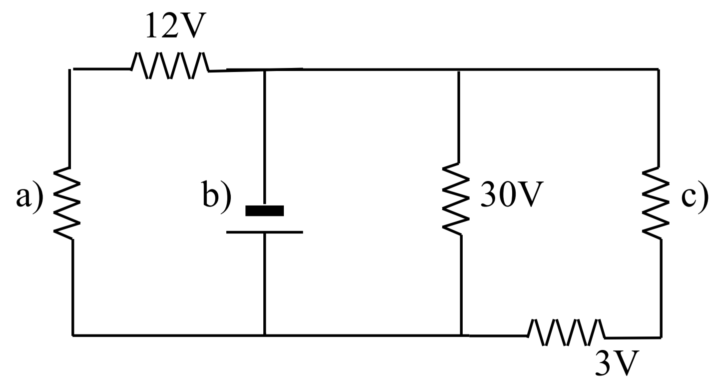
- A chairlift (*battery*) gives skiers (*electrons*) the gravitational potential to "drop" down a ski-slope once they have reached the top of the chair.
- How those skiers get to the bottom depends on the number of runs (*circuit paths*) available to them and which hills (*resistors*, *light bulbs*, etc) they decide to "drop" down, losing potential along the way.
- Connecting wires are analogous to horizontal trails that lead skiers to their runs, since electrons lose almost no potential here. Note that all skiers will have "dropped" their potential once they have reached the bottom of the chair again.

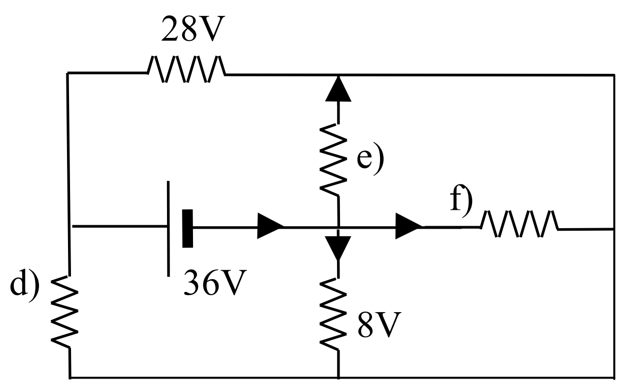
From all this, *Kirchhoff's Voltage Law* was developed: At any connection in an electric circuit, the sum of the potential difference around any closed pathway or loop = 0.

To measure the voltage drop or gain across any device in a circuit properly, a *voltmeter* must be placed in parallel with the device that is being analyzed. The diagram below shows how a voltmeter is attached to correctly measure the potential difference across a 120 V power supply as well as resistor $\mathbf{R_1}$.



Example #5: Determine the unknown voltages for each of the following circuits.





(see Circuitry Ex 5 for answer)